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Aspects influencing man-hour efficiency of kit preparation for mixed-model assembly

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Abstract

Materials supply through kitting can enable space-efficient parts presentation that supports flexibility, quality and efficiency at the assembly stations. However, the preparation of kits is generally associated with considerable man-hour consumption and cost. Within industry, no consensus exists regarding how kit preparation should be designed with respect to man-hour consumption, and literature on the topic is scarce. Based on a literature review and utilizing the experience of an expert panel from industry, the paper uses a cross-case analysis of 15 cases from the automotive industry to identify critical design aspects of kit preparation systems and how they affect man-hour consumption.

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Keywords: Kitting; kit preparation; mixed-model assembly

1. Introduction

Kitting is a materials feeding principle, used in the materials supply to assembly, which has gained increasing attention during the last years, both within industry and in the research literature (see e.g. [1]). This paper deals with the central issue of man-hour efficiency of kit preparation.

When kitting is used, parts are delivered to, and presented at, the assembly stations in pre-sorted kits, where each kit contains parts for one assembly object. Within industry, the most commonly applied alternative to kitting is continuous supply, where a number parts of each part number are stored at the assembly station where they are to be assembled. Compared to continuous supply, kitting can offer advantages in terms of reduced space consumption at workstations, reduced material handling for assemblers, increased assembly support and the potential to reduce quality problems in assembly [2]. Conversely, one of the major drawbacks of using kitting is the man-hours, and associated cost, associated with preparing the kits [2]. Hence, in order to successfully apply kitting within industry, attention should be paid to the design of kit preparation system, in order to ensure efficiency in these operations. A kit preparation system is in the paper considered to consist of the physical setup of the kit preparation station, including layout and equipment, the process design, in terms of e.g. work instructions and routines, as well as the information systems supporting the kit preparation.

Previous research efforts on kitting have dealt with different aspects of the choice of whether or not to use kitting, or on comparing kitting to other materials feeding principles (e.g. [2, 3, 4, 5, 6, 7]) as well as on certain design aspects of kit preparation, such as operations planning [8], kit preparation quality [9] and kit preparation flexibility [10]. There are a few publications addressing man-hour efficiency of kit preparation, but these are far from exhaustive on the topic. Hanson et al. [11] present the results of two experiments studying the effects of batch preparation on man-hour efficiency. Brynzér and Johansson [12] provide a broad overview of aspect relevant to consider when designing kit preparation operations, but do not present conclusive evidence as to how the different aspects can be expected to affect kit preparation performance.

In addition to the literature dealing with kit preparation, several publications address the area of order picking, which can be seen as an area closely related to kit preparation. De Koster et al. [13] define order picking as "the process of retrieving products from storage (or buffer areas) in response

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to a specific customer request”. However, much of the literature dealing with man-hour efficiency of manual order picking revolves around routing of the picker, either by addressing the routing directly, or by addressing how storage policies can affect routing (e.g. [14, 15, 16]). As pointed out by Hanson et al. [11], in small kit preparation areas, which are commonly utilized in the context of materials supply to assembly, the picker tends to follow the same route from cycle to cycle, either traversing a single aisle or moving in a U-shaped pattern.

Within industry, there is no consensus regarding how kit preparation should be designed and several different approaches exist. For example, as pointed out by Hanson et al. [11], batch picking, where several kits are prepared in each kitting cycle, is practiced by some companies, while others choose to prepare one kit at a time. Similarly, there exist different means of conveying picking information to the pickers, utilising e.g. pick-by-light, digital displays, or paper lists [12]. At the same time, it is important to consider the context of the kit preparation, where the context is here considered to encompass the aspects that are beyond the direct influence of the designers of the kit preparation. These aspects thus include physical characteristics of the parts that are included in the kits, as well as production volumes and product variety.

Addressing some of the gaps in the existing literature, the current paper has the purpose of identifying the aspects of both design and context that have the greatest impact on man-hour efficiency of kit preparation. By highlighting the most important aspects to consider, the results of the paper can offer support the design of man-hour efficiency kit preparation.

Next, in Section 2, the paper presents the methodology applied, which is based on 15 case studies and which utilises a workshop with experts from industry. In Section 3, as a basis for the analysis, a list is identified of aspects that are of potential relevance for the man-hour efficiency of kit preparation. Thereafter, in Section 4, the paper presents the outcome of the workshop, which in turn serves as a basis for a focused analysis of the cases, which is presented in Section 5. In Section 6, a discussion of the findings is presented, as well as an outlook towards future research. Section 7 presents the conclusions of the paper.

2. Methodology

The paper includes studies of both literature and empirical data. The current section presents the methodology applied in the paper.

In order to fulfil the purpose of the paper, a list of aspects was first developed of both design and context that could potentially impact man-hour efficiency of kit preparation. This was done firstly based on a review of existing literature. However, since the literature on the topic is not exhaustive, the list of characteristics, of both design and context, which were identified from literature were complemented based on interviews with four experts from industry. The four experts each had extensive industrial experience of working with kit preparation. They represented three different large, globally operating automotive companies: Volvo Cars, Volvo Trucks, and Scania. Two of the experts belonged to the same company, Volvo Trucks, but they belonged to different divisions and operated mainly in different countries. The experts had the following roles within their respective company:

- Manager logistics development at Volvo Cars
- Senior engineer global logistics development at Scania
- Manager internal logistic process & technology at Volvo Trucks
- Senior logistics engineer at Volvo Trucks

The experts were asked to review the list of characteristics identified from literature and to use their experience to confirm or comment upon it, and to complement it with further characteristics. While making different contributions to the list, the four experts from industry were found to be well aligned in terms of opinions. All of the characteristics that had been identified from literature were confirmed by the experts as being likely to affect the man-hour efficiency of kit preparation.

Once the list of characteristics had been developed, cases were identified in which the different characteristics could be studied, where each case represented a different kit preparation system. This was done jointly by the researchers and the four experts. The cases were all identified from assembly plants belonging to the companies or company groups of the experts, so that access was enabled. All in all, 15 cases were selected, including representation from eight different assembly plants in five countries in Europe, Asia and South America, all of which were operating according to mixed-model assembly approach.

Data from each of the cases were collected by use of video recordings of the kit preparation processes, as well as written or oral descriptions of the systems. The video recordings were then analysed according to an approach in line with that of Engström and Medbo [17], in which recordings of manual assembly work are analysed with a computer that is synchronised with the video recorder. Through this preliminary analysis, the time spent on each of a number of predefined activities could be determined for each of the cases, including the activities of picking, walking, and package handling.

A large number of characteristics of both design and context were studied in each case, making it difficult to draw conclusions regarding how each of these characteristics affected man-hour efficiency based solely on how the time spent on each of the predefined activities differed between the cases. Therefore, the preliminary analysis of the video recordings was complemented by a workshop, conducted during one day, where a further analysis of the cases was performed. The workshop panel included all of the four experts from industry, together with six further practitioners and three researchers, of which two were the authors of the paper. The researchers led the workshop, directing its focus, but had a passive role when it came to analyzing the cases, leaving it to the representatives from industry to lead the identification of important aspects in the different cases. During the workshop, an analysis was made of video clips from the different cases, together with written descriptions of design and context of each case, and together with the results from the preliminary analyses of the video recording.

The workshop panel performed the analysis intuitively, utilising their expertise when watching the film clips and reviewing the data from the cases. This analysis cannot easily be captured in written format. Instead, as presented in Section 5, the aspects of design and context, identified as the most important in the workshop, were used as a point of departure for a focused analysis, performed after the workshop. Disregarding the aspects that were not found central during the workshop, the focused analysis thus tried to determine how well the importance of the aspects identified during the workshop was supported by the empirical evidence from the case studies. Particular interest was here paid to the cases where the average time per picked part was the shortest and the longest, respectively, as these extremes were likely to provide insight into aspects that affect the average time per picked part.

3. Characteristics of kit preparation relevant in relation to man-hour efficiency

The aspects identified in the study, both from literature and by the experts from industry as described in Section 2, are presented in Tables 1 and 2, where Table 1 presents aspects of the design of the kit preparation and Table 2 presents aspects of the context. While the distinction between "design" and "context" may not be obvious, and while it may in practice differ from system to system depending on e.g. the authority of the system designer, the paper views the aspects of "design" to be those aspects that the designer of the kit preparation system is likely to have influence over, while the aspects of "context" accordingly are viewed as aspects that are likely to be beyond the direct influence of the designer.

The focus differs between the papers that were reviewed. Several papers discuss the choice between kitting and line stocking for materials feeding [2, 3, 6, 7, 20], whereas others focus only on kitting [1, 8]. Some papers discuss kitting and order picking at assembly line work stations [18, 19, 21], while others focus on order picking in warehouses [14, 15, 16]. Two of the papers focus on performance in the kit preparation regarding execution and picking techniques [11, 12].

Table 1. The aspects of design identified as potentially important for the man-hour efficiency of kit preparation.

Aspects	References
Batch size	[6, 11]
Customisation of kit container	*Proposed by industry experts*
Distance between kit container and component racks	[8]
Information system	[2, 11, 12, 14]
Layout of picking area	[6, 8, 11, 12, 16]
Location of picking system	[2, 3, 6, 12, 18]
Moving or stationary kit container	[14]
No. of pickers working simultaneously	*Proposed by industry experts*
Picker - who prepares the kits?	[2, 12, 11, 18]
Size of picking area (m2)	[3, 11, 12, 14, 16]
Tasks included in picking cycle	[11, 12]
Type and size of storage packages	[3, 7, 11, 19]
Type and design of rack for storage packages	[3, 6, 12, 16, 19]
Type, size and configuration of kit packaging/carrier	[8, 12]

Table 2. The aspects of context identified as potentially important for the man-hour efficiency of kit preparation.

Aspects	References
Amount of part numbers in kit preparation area	[3, 8, 16]
Demand on positioning of part in kit packaging/carrier	[8, 14]
Demand on traceability	*Proposed by industry experts*
Extensive packaging handling?	*Proposed by industry experts*
Height of operators	[19]
Kit production volumes	*Proposed by industry experts*
Lifting aid required?	*Proposed by industry experts*
Number of parts per kit	[8, 11, 16]
Number of picks per hour	[16]
Part "pickability": ease of grasp and handling	[7]
Part commonality (within kit or batch)	[5, 6, 7, 11, 16]
Part sensitivity	[7, 8]
Part size	[5, 6, 7, 8, 12, 20]
Part weight	[5, 7, 8, 20]
Standard kits or not	*Proposed by industry experts*
Type of product	[8]

4. Outcome of the workshop

In the analysis of the workshop, the workshop panel identified, for each case, the aspects of both design and context that had the greatest impact on the man-hour efficiency of the kit preparation. Table 3 presents the list of aspects that, over the 15 cases, were the most commonly identified as having a great impact. Each of the aspects included in the list were identified in at least 5 of the cases as having a great impact on the man-hour efficiency of the kit preparation. The aspects are presented in descending order, based on the number of cases in which they were highlighted.

Table 3. The aspects of design and context identified the 15 cases as being the most important for the man-hour efficiency of kit preparation.

Design aspects	Contextual aspects
Information system	Number of parts per kit
Type and size of storage packages	Part size
Type, size and configuration of kit packaging/carrier	Amount of part numbers in kit preparation area
Type and design of rack for storage packages	
Batch size	
Layout of picking area	
Moving or stationary kit container	
Size of picking area	

Concluding the workshop, the participants were asked to summarise the main findings of the workshop. The workshop panel then emphasised four main design areas that were found to be especially important. While the format of the design areas did not strictly adhere to the format of the aspects identified before the workshop, the aspects and the design areas were well aligned in terms of content.

The four areas were 1) a high density of kit preparation areas, so that the average distance traversed between picks was as small as possible, 2) a picking information system that supports picking in high density areas, providing timely information in an easily accessible format, 3) a process where the kit containers are moved through the kit preparation area during picking, instead of having a stationary container and letting the picker move back and forth between component racks and kit container, 4) having the parts easily accessible in the packages from which they are picked and having kit containers into which the parts can be easily placed. These conclusions thus corresponded very well with the aspects most frequently identified as important from the 15 cases, as presented in Table 3.

5. Focused analysis of the cases

Table 4 presents characteristics of each of the 15 cases, describing the aspects that were identified as being the most important during the workshop. In the table, the cases are numbered based on the average time for picking each part, so that case 1 had the shortest average time per picked part and case 15 the longest. In line with the reasoning of the workshop panel, the table further includes a measure of the density of the respective kit preparation area, here defined as the number of picks per cycle, divided by the number of square metres available to the picker, i.e. not including the area occupied by component racks. This measure of density incorporates many of the aspects identified as important during the workshop, as presented in Table 3. The picking density is related to the following design aspects:

- Type and size of storage packages
- Type and design of rack for storage packages
- Batch size
- Size of picking area

It is also related to the following aspects of the context:

- Number of parts per kit
- Amount of part number in kit preparation area

It can be noted that there exist other definitions of picking density, or pick density. For example, Chan and Chan [16] define pick density as the number of items per order divided by the total number of items in the warehouse. The choice to use a different definition here reflected the focus of the workshop panel on picks per square metres.

Comparing the time per picked part with the density of the kit preparation areas, it seems there is a negative correlation, as suggested by the workshop panel, so that a higher density correlates with a shorter time per picked part. In line with these findings, the two cases with the longest average time per picked part, cases 14 and 15, both had a very low picking density. In case 15, which had the longest picking time per part, the kit container was stationary during picking, so that the picker would walk back and forth between the kit container and the component racks, normally picking two parts at a time, before returning to the kit container and placing the parts there. Moreover, case 15 included extensive packaging handling, as

Table 4. Characteristics of the cases: selection based on the aspects identified as the most important during the workshop.

Case no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Picking density	2.98	1.42	1.68	8.1	5.50	1.18	0.47	6.30	1.58	3.30	0.05	1.31	0.53	0.35	0.08
Size of area (m^2)	13.1	16.9	23	10	n/a	7.2	25	30	12.5	30	76	35	23.4	26	25
Racks for storage packages	3 lvls, offset	3 lvls, offset	3 lvls, small	3 lvls, small offset	4 lvls, small offset	4 lvls, small offset	3 lvls, offset	3 lvls, small	5 lvls, small offset	3 lvls, small offset	2 lvls, offset	4 lvls, small offset	3 lvls, small	1 lvl	2 lvls, offset
Area layout	I-shape	I-shape	I-shape	I-shape	I-shape	U-shape	U-shape	I-shape	I-shape	I-shape	I-shape	I-shape	I-shape	I-shape	I-shape
Moving/stationary	Moving	Moving	Moving	Moving	Moving	Moving	Moving	Moving	Stationary	Moving	Stationary	Moving	Moving	Moving	Stationary
Storage package	Mainly boxes	Mainly boxes	Mainly boxes	Mainly boxes	Mainly boxes	Boxes	Mainly boxes	Mainly boxes	Mainly boxes	Mainly boxes	Pallets	Mainly pallets	Mainly boxes	Pallets	Boxes
Batch size	1	1	4	10	12	1	1	14	3	14	1	3	2	4	1
Kit container	Cart	Cart	Box	Box	Box	Box	Cart	Box	Box	Box	Rack	Cart	Cart	Cart	Rack
Information system	Pick-by-Light	Pick-by-Light	Standard kits	Pick-by-Light	Monitor	Pick-by-Light	Paper list	Pick-by-Light	Monitor	Pick-by-Voice	Pick-by-Voice	Paper list	Pick-by-Light	Pick-by-Light	Pick-by-Voice

half of the parts were individually packaged in plastic film. In case 14, a substantial administration contributed to a longer average time for picking each part, as a paper list was manually handled and scanned for each kit in order for the pick-by-light system to be activated, and each kit on average contained only two parts. This is thus an example of how the picking information system can affect the picking time, here in conjunction with the number of parts per kit.

The two cases with the shortest average time per picked part, i.e. cases 1 and 2, were both from the same assembly plant and showed several similarities. These were the cases where the workshop panel found the parts in the component racks to be the most easily accessible, because of the design of the racks for storage packages, where these was a considerable offset between different shelves. Accordingly, this could be seen to support the notion of type and design of rack for storage packages supporting efficient picking. Moreover, cases 1 and 2 were the two cases where each kit on average contained the most part. Many of these parts were small fasteners, which could easily be grabbed several at a time and placed in the kits. While the possibility of grabbing several parts at a time had not been explicitly highlighted beforehand (albeit indirectly brought up, through the aspects of part size, ease of grasp and handling, and number of part numbers per kit), the workshop panel found that it had a major impact on the average picking time per part.

The layout of the kit preparation area was identified by the workshop panel as important for the kit preparation efficiency. In the workshop analysis of the cases, the aspect of layout was highlighted mainly in the sense of the order and position in which the different parts were presented in the component racks, so that the distance between consecutive picks could be kept low. For example, in case 9, the picker had to move back and forth along the component racks, passing some of the picking locations more than once, which was found to affect the average picking time negatively. As presented in Table 4, the data from the cases do not provide any conclusive indication as to whether an I-shaped layout or a U-shaped one is to prefer.

6. Discussion and future research

While the paper has identified aspects of the design and context that have a great impact on the man-hour efficiency of kit preparation, the list is not necessarily exhaustive. Hence, the aspects that were not found to be of central importance in the analysis should not, on account of the findings of the paper, be dismissed as irrelevant. In line with the nature of case studies, the case selection may affect the outcome of the study. Moreover, it should be noted that the paper has mainly identified direct relations that exist between design and performance and between context and performance. There may naturally exist indirect relations too, e.g. so that the location of the kit preparation affects the layout of the kit preparation area, which in turn affects the man-hour efficiency of the kit preparation, as was found by Hanson et al. [22]. However, the nature of the analysis performed in the paper did not fully support the identification of such indirect relations.

All of the data, and all of the industry experts, were from the automotive industry. While this could potentially affect the possibility of generalising the findings to other industries, it is not evident in which way. One of the aspects that could be linked to the type of industry is the part size. As discussed earlier, the part size is also related to aspects such as the size of the storage packages and of the kit carrier, which in turn can affect for example picking density and potential batch sizes in the kit preparation process. However, the part size varied heavily both within and between the different cases, so that both small parts, such as nuts and bolts, and relatively large parts, such as batteries for truck engines, were included in the study. Moreover, the part size was one of the aspects of the context that the paper identified as being the most important. If part sizes in other industries differ from those studied in the paper, this could then be seen as a further indication of the importance of considering this aspect when designing kit preparation processes. All in all, it seems likely that the findings of the paper are relevant also in other mixed-model assembly contexts than in the automotive industry.

Potentially, the experts from industry could have been affected by previous experiences in their analysis of the different cases, bringing old ideas and conceptions into the list of important aspects, rather than actually identifying the aspects from the cases. This risk was mitigated by the involvement of several experts from different companies, with different experiences, so that different perspectives could be included. Moreover, the focused analysis that was performed after the workshop, and presented in Section 5, confirmed that the aspects identified during the workshop were aligned with the empirical data from the cases.

As the focused analysis provides support to the list of aspects from the workshop, the relevance of these aspects in relation to man-hour efficiency of kit preparation is clear. From a practical perspective, the list that has been identified should thus constitute a good starting point for a designer of an industrial kit preparation process, as it highlights aspects that should be considered during the design process. The importance of the picking density, as defined in the paper, is clear and should be considered in the choice of packaging, in the design of racks for storage packages, in the choice of batch size, and in the dimensioning of the picking area.

Many of the mathematical models that have been brought forward in existing kitting literature view the picking time as a constant that is used e.g. as part of a comparison between the feeding principles of kitting and line stocking (e.g. [20]). The current paper highlights the importance that the kitting design can have for the picking time and, thus, for a comparison between these two principles.

For future research, attention could be paid to the relation between different aspects, identifying both how different design aspects relate to each other and how design aspects and contextual aspects relate to each other, so that an appropriate design can be chosen based on the context. In this context, it can be noted that some aspects may be related to both design and context. For example, the size of the picking area was in the paper viewed as a design aspect, as it can be affected by the design of the kit preparation, but the size of the picking area is of course also related to contextual aspects, such as the amount of part numbers in the kit preparation area. Future research could also study the picking information systems further, and their impact on man-hour efficiency of kit preparation. While the picking information system was indicated to be one of the most important design aspects, the empirical data from the cases do not provide any clear indication as to which type of system is preferable, in terms of whether information is conveyed by e.g. Pick-by-Voice, Pick-by-Light or paper lists. The expert panel pointed out the importance of using an information system that is aligned with the rest of the kitting design and that provides timely information in an easily accessible format.

7. Conclusions

Based on existing literature as well as empirical data from 15 case studies, and utilizing the expertise of experts from industry, the paper has identified several aspects that have great impact on man-hour efficiency of kit preparation, including aspects of both design and context. Four main areas were identified as having a strong positive influence on man-hour efficiency: 1) a high density of kit preparation areas, so that the average distance traversed between picks was as small as possible, 2) a picking information system that supports picking in high density areas, providing timely information in an easily accessible format, 3) a process where the kit containers are moved through the kit preparation area during picking, instead of having a stationary container and letting the picker move back and forth between component racks and kit container, 4) having the parts easily accessible in the packages from which they are picked and having kit containers into which the parts can be easily placed.

Previous research has scarcely dealt with the issue of man-hour efficiency of kit preparation and the paper thus makes a clear contribution. Within industry, knowledge of the aspects that affect man-hour efficiency the most can be used to support the design of efficient kit preparation systems and also to support the choice of whether or not to use kitting, as the effects in terms of man-hour consumption can more easily be anticipated.

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